1.1 Natural Gas Systems (CRF Source Category 1B2b)

The U.S. natural gas system encompasses hundreds of thousands of wells, hundreds of processing facilities, and over a million miles of transmission and distribution pipelines. Overall, natural gas systems emitted 165.6 MMT CO_2 Eq. (6,624 kt) of CH_4 in 2017, a 14 percent decrease compared to 1990 emissions, and less than 1 percent decrease compared to 2016 emissions (see [REF _Ref474306638 \h * MERGEFORMAT], [REF _Ref353464237 \h * MERGEFORMAT], and [REF _Ref353464269 \h * MERGEFORMAT]), 26.3 MMT CO_2 Eq. (26,327 kt) of non-combustion CO_2 in 2017, a 12 percent decrease compared to 1990 emissions, and a 3 percent increase compared to 2016 levels, and 0.005 MMT CO_2 Eq. (0.02 kt) of N_2O, a 438 percent increase compared to 1990 emissions.

The 1990 to 2017 trend in CH_4 is not consistent across segments. Overall, the 1990 to 2017 decrease in CH_4 emissions is due primarily to the decrease in emissions from the distribution (73 percent decrease), transmission and storage (43 percent decrease), processing (45 percent decrease), and exploration (69 percent decrease) segments. Over the same time period, the production segment saw increased methane emissions of 62 percent (with onshore production emissions increasing 29 percent, offshore production emissions increasing 7 percent, and gathering and boosting (G&B) emissions increasing 109 percent). The 1990 to 2017 decrease in CO_2 is due primarily to decreases in acid gas removal emissions in the processing segment, where acid gas removal emissions per plant have decreased over time.

Methane and non-combustion CO_2 emissions from natural gas systems include those resulting from normal operations, routine maintenance, and system upsets. Emissions from normal operations include: natural gas engine and turbine uncombusted exhaust, bleed and discharge emissions from pneumatic controllers, and fugitive emissions from system components. Routine maintenance emissions originate from pipelines, equipment, and wells during repair and maintenance activities. Pressure surge relief systems and accidents can lead to system upset emissions. Below is a characterization of the five major stages of the natural gas system. Each of the stages is described and the different factors affecting CH_4 and non-combustion CO_2 emissions are discussed.

Emissions of N_2O from flaring activities are included in the Inventory, with most of the emissions occurring in the processing and production segments.

Each year, some estimates in the Inventory are recalculated with improved methods and/or data. These improvements are implemented consistently across the previous Inventory's time series (i.e., 1990 to 2016) to ensure that the trend is accurate. Recalculations in natural gas systems in this year's Inventory include:

- Updated methodology for G&B pipeline emissions.
- Updated methodology for transmission pipeline blowdown emissions.
- Updated methodology for LNG estimates (emissions for both storage stations and import/export terminals) within the transmission and storage segment.
- Added N_2O emissions that were not previously reported in the Inventory.
- Updated the data source for well drilling activity.
- Recalculations due to GHGRP submission revisions.

The Recalculations Discussion section below provides more details on the updated methods.

Exploration. Exploration includes well drilling, testing, and completions. Emissions from exploration account for 1 percent of CH_4 emissions and 2 percent of CO_2 emissions from natural gas systems in 2017. Well completions account for most of the CH_4 emissions in 2017, with well testing and drilling also contributing emissions. Flaring emissions account for most of the non-combustion CO_2 emissions. Methane emissions from exploration decreased by 69 percent from 1990 to 2017, with the largest decreases coming from hydraulically fractured gas well completions without reduced emissions completions (RECs) or flaring. Methane emissions increased 75 percent from 2016 to 2017 due to increases in emissions from completions, mostly from hydraulically fractured well completions with RECs without flaring. Methane emissions were highest from 2006 to 2008. Carbon dioxide

emissions from exploration increased by 18 percent from 1990 to 2017, and by 149 percent from 2016 to 2017 due to increases in flaring. Carbon dioxide emissions were highest from 2006 to 2008. Nitrous oxide emissions decreased 37 percent from 1990 to 2017, and increased 156 percent from 2016 to 2017.

Production (including gathering and boosting). In the production stage, wells are used to withdraw raw gas from underground formations. Emissions arise from the wells themselves, and well-site gas treatment equipment such as dehydrators and separators. Gathering and boosting emission sources are included within the production sector. The gathering and boosting sources include gathering and boosting stations (with multiple emission sources on site) and gathering pipelines. The gathering and boosting stations receive natural gas from production sites and transfer it, via gathering pipelines, to transmission pipelines or processing facilities (custody transfer points are typically used to segregate sources between each segment). Emissions from production (including gathering and boosting) account for 65 percent of CH_4 emissions and 11 percent of non-combustion CO_2 emissions from natural gas systems in 2017. Emissions from compressors, pneumatic controllers, and offshore platforms account for most of the CH_4 emissions in 2017. Flaring emissions account for most of the non-combustion CO_2 emissions with the highest emissions coming from miscellaneous production flaring, flaring to control tank emissions, and offshore flaring. National total dry gas production in the U.S. increased by 53 percent from 1990 to 2017, and by 3 percent from 2016 to 2017. Methane emissions from production increased by 62 percent from 1990 to 2017, due primarily to increases in emissions from pneumatic controllers (due to an increase in the number of controllers, particularly in the number of intermittent bleed controllers) and increases in emissions from gathering and boosting stations . Methane emissions increased 1 percent from 2016 to 2017 due to increases in emissions from gathering and boosting stations and hydraulically fractured well workovers with RECs and venting. Carbon dioxide emissions from production increased by 175 percent from 1990 to 2017 due to increases in flaring, and decreased 11 percent from 2016 to 2017 due primarily to a decrease in emissions from large tanks with flares. Nitrous oxide emissions increased 480 percent from 1990 to 2017 and decreased 8 percent from 2016 to 2017.

Processing. In this stage, natural gas liquids and various other constituents from the raw gas are removed, resulting in "pipeline quality" gas, which is injected into the transmission system. Fugitive CH_4 emissions from compressors, including compressor seals, are the primary emission source from this stage. Most of the non-combustion CO_2 emissions come from acid gas removal (AGR) units, which are designed to remove CO_2 from natural gas. Processing plants account for 7 percent of CH_4 emissions and 85 percent of non-combustion CO_2 emissions from natural gas systems. Methane emissions from processing decreased by 45 percent from 1990 to 2017 as emissions from compressors (leaks and venting) and equipment leaks decreased, and increased 3 percent from 2016 to 2017 due to increased emissions from centrifugal and reciprocating compressors. Carbon dioxide emissions from processing decreased by 21 percent from 1990 to 2017, due to a decrease in acid gas removal emissions, and increased 3 percent from 2016 to 2017 due to increased emissions from flaring. Nitrous oxide emissions increased from 1990 to 2017, and have decreased 20 percent from 2016 to 2017.

Transmission and Storage. Natural gas transmission involves high pressure, large diameter pipelines that transport gas long distances from field production and processing areas to distribution systems or large volume customers such as power plants or chemical plants. Compressor station facilities are used to move the gas throughout the U.S. transmission system. Leak CH_4 emissions from these compressor stations and venting from pneumatic controllers account for most of the emissions from this stage. Uncombusted engine exhaust and pipeline venting are also sources of CH_4 emissions from transmission. Natural gas is also injected and stored in underground formations, or liquefied and stored in above ground tanks, during periods of low demand (e.g., summer), and withdrawn, processed, and distributed during periods of high demand (e.g., winter). Compressors and dehydrators are the primary contributors to emissions from storage. Emissions from LNG are also included under transmission and storage. Methane emissions from the transmission and storage sector account for approximately 20 percent of emissions from natural gas systems, while CO_2 emissions from transmission and storage account for 2 percent of the non-combustion CO_2 emissions from natural gas systems. CH_4 emissions from this source decreased by 43 percent from 1990 to 2017 due to reduced compressor station emissions (including emissions from compressors and leaks), and decreased 6 percent from 2016 to 2017 due to reduced pipeline venting and plugging of the Aliso Canyon leak. CO_2 emissions from transmission and storage have increased by 147 percent from 1990 to 2017, and by 45 percent from 2016 to 2017, due to increased emissions from LNG export terminals. The quantity of LNG exported from the U.S. increased by a factor of 12 from 1990 to 2017, and by 279 percent from 2016 to 2017. LNG emissions are about 2 percent of CH_4 and 74 percent of CO_2 emissions from transmission and storage in year 2017. Nitrous oxide emissions from transmission and storage increased by 79 percent from 1990 to 2017 and increased 22 percent from 2016 to 2017.

Distribution. Distribution pipelines take the high-pressure gas from the transmission system at "city gate" stations, reduce the pressure and distribute the gas through primarily underground mains and service lines to individual end users. There were 1,294,091 miles of distribution mains in 2017, an increase of nearly 350,000 miles since 1990 (PHMSA 2018). Distribution system emissions, which account for 7 percent of CH_4 emissions from natural gas systems and less than 1 percent of non-combustion CO_2 emissions, result mainly from leak emissions from pipelines and stations. An increased use of plastic piping, which has lower emissions than other pipe materials, has reduced both CH_4 and CO_2 emissions from this stage, as have station upgrades at metering and regulating (M&R) stations. Distribution system CH_4 emissions in 2017 were 73 percent lower than 1990 levels (changed from 43.5 MMT CO_2 Eq. to 11.9 MMT CO_2 Eq.) and 1 percent lower than 2016 emissions, while distribution CO_2 emissions in 2017 were also 73 percent lower than 1990 levels and 1 percent lower than 2016 Emissions. CO_2 emission from this segment are less than 0.1 MMT CO_2 Eq. across the time series.

Total CH_4 emissions for the five major stages of natural gas systems are shown in MMT CO_2 Eq. ([REF _Ref474306638 \h * MERGEFORMAT]) and kt ([REF _Ref353464237 \h * MERGEFORMAT]). [REF _Ref353464269 \h * MERGEFORMAT] provides additional information on how the estimates in [REF _Ref317250364 \h * MERGEFORMAT] were calculated. With recent updates to the Inventory, most emissions are calculated using a net emission approach. However, certain sources are still calculated with a potential emission approach. [REF _Ref353464269 \h * MERGEFORMAT] shows the calculated potential CH_4 release (i.e., potential emissions before any controls are applied) from each stage, and the amount of CH_4 that is estimated to have been flared, captured, or otherwise controlled, and therefore not emitted to the atmosphere. Subtracting the value for CH_4 that is controlled, from the value for calculated potential release of CH_4, results in the total net emissions values. More disaggregated information on potential emissions and emissions is available in Annex 3.6. See Methodology for Estimating CH_4 and CO_2 Emissions from Natural Gas Systems.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: CH_4 Emissions from Natural Gas Systems (MMT CO_2 Eq.)[a]

Stage	1990	2005	2013	2014	2015	2016	2017
Exploration[b]	**4.0**	**10.9**	**3.0**	**1.0**	**1.0**	**0.7**	**1.2**
Production	**67.0**	**89.5**	**108.5**	**108.5**	**108.8**	**107.1**	**108.4**
Onshore Production	35.0	51.5	53.3	49.3	47.2	46.0	45.1
Offshore Production	3.5	4.3	3.8	3.8	3.8	3.8	3.8
Gathering and Boosting[c]	28.5	33.7	51.4	55.4	57.9	57.4	59.5
Processing	**21.3**	**11.6**	**10.8**	**11.1**	**11.1**	**11.4**	**11.7**
Transmission and Storage	**57.2**	**36.1**	**31.0**	**32.4**	**34.2**	**34.5**	**32.4**
Distribution	**43.5**	**23.3**	**12.3**	**12.2**	**12.0**	**12.0**	**11.9**
Total	**193.1**	**171.4**	**165.6**	**165.1**	**167.2**	**165.7**	**165.6**

[a] These values represent CH_4 emitted to the atmosphere. CH_4 that is captured, flared, or otherwise controlled (and not emitted to the atmosphere) has been calculated and removed from emission totals.
[b] Exploration includes well drilling, testing, and completions.
[c] Gathering and boosting includes gathering and boosting station routine vented and leak sources, gathering pipeline leaks and blowdowns, and gathering and boosting station episodic events.
Note: Totals may not sum due to independent rounding.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: CH_4 Emissions from Natural Gas Systems (kt)[a]

Stage	1990	2005	2013	2014	2015	2016	2017
Exploration[b]	**162**	**437**	**119**	**39**	**42**	**28**	**49**
Production	**2,679**	**3,578**	**4,340**	**4,338**	**4,353**	**4,286**	**4,337**
Onshore Production	1,399	2,058	2,133	1,972	1,888	1,840	1,806
Offshore Production	141	173	151	151	151	151	151
Gathering and Boosting[c]	1,139	1,347	2,056	2,216	2,315	2,295	2,380
Processing	**853**	**464**	**432**	**443**	**443**	**456**	**469**
Transmission and Storage	**2,289**	**1,444**	**1,239**	**1,295**	**1,368**	**1,380**	**1,295**
Distribution	**1,741**	**932**	**494**	**487**	**481**	**480**	**475**
Total	**7,723**	**6,856**	**6,624**	**6,603**	**6,686**	**6,629**	**6,624**

[a] These values represent CH_4 emitted to the atmosphere. CH_4 that is captured, flared, or otherwise controlled (and not emitted to the atmosphere) has been calculated and removed from emission totals.

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[b] Exploration includes well drilling, testing, and completions.
[c] Gathering and boosting includes gathering and boosting station routine vented and leak sources, gathering pipeline leaks and blowdowns, and gathering and boosting station episodic events.
Note: Totals may not sum due to independent rounding.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: Calculated Potential CH_4 and Captured/Combusted CH_4 from Natural Gas Systems (MMT CO_2 Eq.)

	1990	2005	2013	2014	2015	2016	2017
Calculated Potential[a]	**193.1**	**182.0**	**179.0**	**178.4**	**180.5**	**179.1**	**179.0**
Exploration	4.0	10.9	3.0	1.0	1.0	0.7	1.2
Production	67.0	94.8	115.2	115.1	115.5	113.8	115.1
Processing	21.3	11.6	10.8	11.1	11.1	11.4	11.7
Transmission and Storage	57.2	41.4	37.7	39.1	40.9	41.2	39.1
Distribution	43.5	23.3	12.3	12.2	12.0	12.0	11.9
Captured/Combusted	**0.0**	**10.6**	**13.4**	**13.4**	**13.4**	**13.4**	**13.4**
Exploration	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Production	0.0	5.3	6.7	6.7	6.7	6.7	6.7
Processing	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Transmission and Storage	0.0	5.3	6.7	6.7	6.7	6.7	6.7
Distribution	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Net Emissions	**193.1**	**171.4**	**165.6**	**165.1**	**167.2**	**165.7**	**165.6**
Exploration	4.0	10.9	3.0	1.0	1.0	0.7	1.2
Production	67.0	89.5	108.5	108.5	108.8	107.1	108.4
Processing	21.3	11.6	10.8	11.1	11.1	11.4	11.7
Transmission and Storage	57.2	36.1	31.0	32.4	34.2	34.5	32.4
Distribution	43.5	23.3	12.3	12.2	12.0	12.0	11.9

[a] In this context, "potential" means the total emissions calculated before voluntary reductions and regulatory controls are applied.
NA (Not Applicable)
Note: Totals may not sum due to independent rounding.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: Non-combustion CO_2 Emissions from Natural Gas Systems (MMT)

Stage	1990	2005	2013	2014	2015	2016	2017
Exploration	0.4	1.8	1.3	0.8	0.3	0.2	0.5
Production	1.0	1.8	3.1	3.3	3.4	3.2	2.8
Processing	28.3	18.9	20.5	21.0	21.0	21.7	22.5
Transmission and Storage	0.2	0.2	0.3	0.3	0.3	0.4	0.5
Distribution	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Total	**30.0**	**22.6**	**25.1**	**25.5**	**25.1**	**25.5**	**26.3**

+ Does not exceed 0.1 MMT CO_2 Eq.
Note: Totals may not sum due to independent rounding.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: Non-combustion CO_2 Emissions from Natural Gas Systems (kt)

Stage	1990	2005	2013	2014	2015	2016	2017
Exploration	409	1,756	1,281	843	291	194	483
Production	1,035	1,759	3,076	3,342	3,448	3,188	2,845
Processing	28,338	18,876	20,510	21,047	21,047	21,724	22,452
Transmission and Storage	216	219	267	272	271	368	533
Distribution	51	27	15	14	14	14	14
Total	**30,048**	**22,638**	**25,148**	**25,518**	**25,071**	**25,488**	**26,327**

Note: Totals may not sum due to independent rounding.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: N_2O Emissions from Natural Gas Systems (Metric Tons CO_2 Eq.)

Stage	1990	2005	2013	2014	2015	2016	2017
Exploration	461	1,401	1,179	855	3,215	113	289
Production	162	900	2,330	1,997	2,773	1,019	937
Processing	NO	3,351	5,625	5,772	5,772	3,802	3,049
Transmission and Storage	257	309	341	344	347	377	461
Distribution	NO	NO	NO	NO	NO	NO	NO
Total	**880**	**5,961**	**9,476**	**8,969**	**12,107**	**5,311**	**4,735**

NO (Not Occurring)
Note: Totals may not sum due to independent rounding.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: N_2O Emissions from Natural Gas Systems (Metric Tons N_2O)

Stage	1990	2005	2013	2014	2015	2016	2017
Exploration	1.5	4.7	4.0	2.9	10.8	0.4	1.0
Production	0.5	3.0	7.8	6.7	9.3	3.4	3.1
Processing	NO	11.2	18.9	19.4	19.4	12.8	10.2
Transmission and Storage	0.9	1.0	1.1	1.2	1.2	1.3	1.5
Distribution	NO	NO	NO	NO	NO	NO	NO
Total	**3.0**	**20.0**	**31.8**	**30.1**	**40.6**	**17.8**	**15.9**

NO (Not Occurring)
Note: Totals may not sum due to independent rounding.

Methodology

See Annex 3.6 for the full time series of emissions data, activity data, and emission factors, and additional information on methods and data sources—for example, the specific years of reporting data from EPA's Greenhouse Gas Reporting Program (GHGRP) that are used to develop certain factors.

This section provides a general overview of the methodology for natural gas emission estimates in the Inventory, which involves the calculation of CH_4, CO_2, and N_2O emissions for over 100 emissions sources, and then the summation of emissions for each natural gas segment.

The approach for calculating emissions for natural gas systems generally involves the application of emission factors to activity data. For most sources, the approach uses technology-specific emission factors or emission factors that vary over time and take into account changes to technologies and practices, which are used to calculate net emissions directly. For others, the approach uses what are considered "potential methane factors" and reduction data to calculate net emissions.

Emission Factors. Key references for emission factors for CH_4 and non-combustion-related CO_2 emissions from the U.S. natural gas industry include a 1996 study published by the Gas Research Institute (GRI) and EPA (GRI/EPA 1996), the EPA's GHGRP (EPA 2018), and others.

The EPA/GRI study developed over 80 CH_4 emission factors to characterize emissions from the various components within the operating stages of the U.S. natural gas system. The EPA/GRI study was based on a combination of process engineering studies, collection of activity data, and measurements at representative gas facilities conducted in the early 1990s. Year-specific natural gas CH_4 compositions are calculated using U.S. Department of Energy's Energy Information Administration (EIA) annual gross production for National Energy Modeling System (NEMS) oil and gas supply module regions in conjunction with data from the Gas Technology Institute (GTI, formerly GRI) Unconventional Natural Gas and Gas Composition Databases (GTI 2001). These year-specific CH_4 compositions are applied to emission factors, which therefore may vary from year to year due to slight changes in the CH_4 composition for each NEMS region.

GHGRP Subpart W data were used to develop CH_4, CO_2, and N_2O emission factors for several sources in the Inventory. In the onshore production segment, GHGRP data were used to develop emission factors used for all time

series years for well testing, gas well completions and workovers with and without hydraulic fracturing, pneumatic controllers and chemical injection pumps, condensate tanks, liquids unloading, miscellaneous flaring, and gathering and boosting pipelines. In the processing segment, for recent years of the times series, GHGRP data were used to develop emission factors for fugitives, compressors, flares, dehydrators, and blowdowns/venting. In the transmission and storage segment, GHGRP data were used to develop factors for all time series years for LNG stations and terminals and transmission pipeline blowdowns, and for pneumatic controllers for recent years of the times series.

Other data sources used for CH_4 emission factors include Zimmerle et al. (2015) for transmission and storage station fugitives and compressors, and Lamb et al. (2015) for recent years for distribution pipelines and meter/regulator stations.

For sources in the exploration, production and processing segments that use emission factors not directly calculated from GHGRP data, data from the 1996 GRI/EPA study and a 2001 GTI publication were used to adapt the CH_4 emission factors into non-combustion related CO_2 emission factors. For sources in the transmission and storage segment that use emission factors not directly calculated from GHGRP data, and for sources in the distribution segment, data from the 1996 GRI/EPA study and a 1993 GTI publication were used to adapt the CH_4 emission factors into non-combustion related CO_2 emission factors. See Annex 3.6 for more detailed information on the methodology and data used to calculate CH_4 and non-combustion CO_2 and N_2O emissions from natural gas systems.

Activity Data. Activity data were taken from various published data sets, as detailed in Annex 3.6. Key activity data sources include data sets developed and maintained by EPA's GHGRP; DrillingInfo, Inc. (DrillingInfo 2018); U.S. Department of the Interior's Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE, previously Minerals and Management Service); Federal Energy Regulatory Commission (FERC); EIA; the Natural Gas STAR Program annual emissions savings data; Oil and Gas Journal; PHMSA; the Wyoming Conservation Commission; and the Alabama State Oil and Gas Board.

For a few sources, recent direct activity data are not available. For these sources, either 2016 data were used as a proxy for 2017 data, or a set of industry activity data drivers was developed and used to calculate activity data over the time series. Drivers include statistics on gas production, number of wells, system throughput, miles of various kinds of pipe, and other statistics that characterize the changes in the U.S. natural gas system infrastructure and operations. More information on activity data and drivers is available in Annex 3.6.

A complete list of references for emission factors and activity data by emission source is provided in Annex 3.6.

Calculating Net Emissions. For most sources, net emissions are calculated directly by applying emission factors to activity data. Emission factors used in net emission approaches reflect technology-specific information, and take into account regulatory and voluntary reductions. However, for certain sectors, some sources are calculated using potential emission factors, and the step of deducting CH_4 that is not emitted from the total CH_4 potential estimates to develop net CH_4 emissions is applied. To take into account use of such technologies and practices that result in lower emissions but are not reflected in "potential" emission factors, data are collected on both regulatory and voluntary reductions. Regulatory actions addressed using this method include National Emission Standards for Hazardous Air Pollutants (NESHAP) regulations for dehydrator vents. Voluntary reductions included in the Inventory are those reported to Natural Gas STAR for certain sources in the production and transmission and storage segments.

In fall of 2015, a well in a California storage field began leaking methane at an initial average rate of around 50 metric tons (MT) of methane (CH_4) an hour, and continued leaking until it was permanently sealed in February of 2016.[1] An emission estimate from the leak event was included for 2015 and 2016, using the estimate of the leak published by the California Air Resources Board (99,638 MT CH_4 for the duration of the leak). The 2015 and 2016 emission estimates of 78,350 MT CH_4 and 21,288 MT CH_4, respectively, were added to the 2015 and 2016 estimates of fugitive emissions from storage wells. For more information, please see *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2015: Update for Storage Segment Emissions*.[2]

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[1] For more information on the Aliso Canyon event, and the measurements conducted of the leak, please see Ensuring Safe and Reliable Underground Natural Gas Storage, *Final Report of the Interagency Task Force on Natural Gas Storage Safety*, available at <http://www.energy.gov/sites/prod/files/2016/10/f33/Ensuring%20Safe%20and%20Reliable%20Underground%20Natural%20Gas%20Storage%20-%20Final%20Report.pdf>.

[2] <https://www.epa.gov/ghgemissions/natural-gas-and-petroleum-systems-ghg-inventory-additional-information-1990-2015-ghg>.

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Through EPA's stakeholder process on oil and gas in the Inventory, EPA received initial stakeholder feedback on updates under consideration for the Inventory. Stakeholder feedback is noted below in Uncertainty and Time-Series Consistency, Recalculations Discussion, and Planned Improvements.

Uncertainty and Time-Series Consistency

In recent years, EPA has made significant revisions to the Inventory methodology to use updated activity and emissions data. To update its characterization of uncertainty, EPA has conducted a quantitative uncertainty analysis using the IPCC Approach 2 methodology (Monte Carlo Simulation technique). For more information, please see the memorandum *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2016: Natural Gas and Petroleum Systems Uncertainty Estimates (2018 Uncertainty Memo).*[3] EPA used Microsoft Excel's @RISK add-in tool to estimate the 95 percent confidence bound around CH_4 emissions from natural gas systems for the current Inventory, then applied the calculated bounds to both CH_4 and CO_2 emissions estimates. For the analysis, EPA focused on the 14 highest-emitting sources for the year 2016, which together emitted 76 percent of methane from natural gas systems in 2017, and extrapolated the estimated uncertainty for the remaining sources. The @RISK add-in provides for the specification of probability density functions (PDFs) for key variables within a computational structure that mirrors the calculation of the inventory estimate. The IPCC guidance notes that in using this method, "some uncertainties that are not addressed by statistical means may exist, including those arising from omissions or double counting, or other conceptual errors, or from incomplete understanding of the processes that may lead to inaccuracies in estimates developed from models." The uncertainty bounds reported below only reflect those uncertainties that EPA has been able to quantify and do not incorporate considerations such as modeling uncertainty, data representativeness, measurement errors, misreporting or misclassification. The understanding of the uncertainty of emission estimates for this category evolves and improves as the underlying methodologies and datasets improve.

The results presented below provide the 95 percent confidence bound within which actual emissions from this source category are likely to fall for the year 2017, using the IPCC methodology. The results of the Approach 2 uncertainty analysis are summarized in [REF _Ref448049979 \h * MERGEFORMAT]. Natural gas systems CH_4 emissions in 2017 were estimated to be between 141.8 and 193.3 MMT CO2 Eq. at a 95 percent confidence level. Natural gas systems CO_2 emissions in 2017 were estimated to be between 22.5 and 30.7 MMT CO_2 Eq. at a 95 percent confidence level. Uncertainty bounds for other years of the time series have not been calculated, but uncertainty is expected to vary over the time series. For example, years where many emission sources are calculated with interpolated data would likely have higher uncertainty than years with predominantly year-specific data.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: Approach 2 Quantitative Uncertainty Estimates for CH_4 and Non-combustion CO_2 Emissions from Natural Gas Systems (MMT CO_2 Eq. and Percent)

Source	Gas	2017 Emission Estimate (MMT CO_2 Eq.)[b]	Uncertainty Range Relative to Emission Estimate[a] (MMT CO_2 Eq.)		(%)	
			Lower Bound[b]	Upper Bound[b]	Lower Bound[b]	Upper Bound[b]
Natural Gas Systems	CH_4	165.6	141.8	193.3	-14%	+17%
Natural Gas Systems[c]	CO_2	26.3	22.5	30.7	-14%	+17%

[a] Range of emission estimates estimated by applying the 95 percent confidence intervals obtained from the Monte Carlo Simulation analysis conducted for the year 2017 CH_4 emissions.

[b] All reported values are rounded after calculation. As a result, lower and upper bounds may not be duplicable from other rounded values as shown in [REF _Ref474306638 \h * MERGEFORMAT] and [REF _Ref447884352 \h * MERGEFORMAT].

[c] An uncertainty analysis for the CO_2 emissions was not performed. The relative uncertainty estimated (expressed as a percent) from the CH_4 uncertainty analysis was applied to the point estimate of CO_2 emissions.

GHGRP data available (starting in 2011) and other recent data sources have improved estimates of emissions from natural gas systems. To develop a consistent time series, for sources with new data, EPA reviewed available information on factors that may have resulted in changes over the time series (e.g., regulations, voluntary actions)

[3] See < https://www.epa.gov/ghgemissions/natural-gas-and-petroleum-systems>.

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and requested stakeholder feedback on trends as well. For most sources, EPA developed annual data for 1993 through 2010 by interpolating activity data or emission factors or both between 1992 and 2011 data points. Information on time-series consistency for sources updated in this year's Inventory can be found in the Recalculations Discussion below, with additional detail provided in supporting memos (relevant memos are cited in the Recalculations Discussion). For detailed documentation of methodologies, please see Annex 3.5.

QA/QC and Verification Discussion

The natural gas emission estimates in the Inventory are continually being reviewed and assessed to determine whether emission factors and activity factors accurately reflect current industry practices. A QA/QC analysis was performed for data gathering and input, documentation, and calculation. QA/QC checks are consistently conducted to minimize human error in the model calculations. EPA performs a thorough review of information associated with new studies, GHGRP data, regulations, public webcasts, and the Natural Gas STAR Program to assess whether the assumptions in the Inventory are consistent with current industry practices. The EPA has a multi-step data verification process for GHGRP data, including automatic checks during data-entry, statistical analyses on completed reports, and staff review of the reported data. Based on the results of the verification process, the EPA follows up with facilities to resolve mistakes that may have occurred.[4]

As in previous years, EPA conducted early engagement and communication with stakeholders on updates prior to public review. EPA held a stakeholder workshop on greenhouse gas data for oil and gas in October of 2018, and webinars in June of 2018 and February of 2019. EPA released memos detailing updates under consideration and requesting stakeholder feedback. Stakeholder feedback received through these processes is discussed in the Recalculations Discussion and Planned Improvements sections below.

In recent years, several studies have measured emissions at the source level and at the national or regional level and calculated emission estimates that may differ from the Inventory. There are a variety of potential uses of data from new studies, including replacing a previous estimate or factor, verifying or QA of an existing estimate or factor, and identifying areas for updates. In general, there are two major types of studies related to oil and gas greenhouse gas data: studies that focus on measurement or quantification of emissions from specific activities, processes and equipment, and studies that use tools such as inverse modeling to estimate the level of overall emissions needed to account for measured atmospheric concentrations of greenhouse gases at various scales. The first type of study can lead to direct improvements to or verification of Inventory estimates. In the past few years, EPA has reviewed and in many cases, incorporated data from these data sources. The second type of study can provide general indications on potential over- and under-estimates. A key challenge in using these types of studies to assess Inventory results is having a relevant basis for comparison (i.e., the independent study should assess data from the Inventory and not another data set, such as EDGAR.). In an effort to improve the ability to compare the national-level inventory with measurement results that may be at other scales, a team at Harvard University along with EPA and other coauthors developed a gridded inventory of U.S. anthropogenic methane emissions with 0.1° x 0.1° spatial resolution, monthly temporal resolution, and detailed scale-dependent error characterization.[5] The gridded methane inventory is designed to be consistent with the 2016 *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014* estimates for the year 2012, which presents national totals.[6]

Recalculations Discussion

EPA received information and data related to the emission estimates through GHGRP reporting, the annual Inventory formal public notice periods, stakeholder feedback on updates under consideration, and new studies. In June, October and November 2018, EPA released draft memoranda that discussed changes under consideration, and requested stakeholder feedback on those changes.[7] Memoranda cited in the Recalculations Discussion below are: *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2017: Updates Under Consideration for Natural Gas*

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[4] See <https://www.epa.gov/sites/production/files/2015-07/documents/ghgrp_verification_factsheet.pdf>.

[5] See <https://www.epa.gov/ghgemissions/gridded-2012-methane-emissions>.

[6] See <https://www.epa.gov/ghgemissions/us-greenhouse-gas-inventory-report-1990-2014>.

[7] Stakeholder materials including EPA memoranda for the current (i.e., 1990 to 2017) Inventory are available at <https://www.epa.gov/ghgemissions/natural-gas-and-petroleum-systems>.

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Gathering & Boosting Emissions (*Oct. 2018 G&B* memo), *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2017: Updates Under Consideration for Liquefied Natural Gas Segment Emissions* (*Oct. 2018 LNG* memo), and *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2017: Other Updates Under Consideration* (*Nov. 2018 Other Updates* memo).

EPA thoroughly evaluated relevant information available and made several updates to the Inventory, including: using GHGRP data to calculate emissions from gathering pipelines, transmission pipeline blowdowns, and LNG storage stations and terminals; calculating new N_2O emission factors for flaring sources throughout all segments directly from GHGRP data; and updating the data source for well drilling activity. In addition, certain sources did not undergo methodological updates, but CH_4 and/or CO_2 emissions changed by greater than 0.05 MMT CO_2 Eq., comparing the previous estimate for 2016 to the current (recalculated) estimate for 2016 (the emissions changes were mostly due to GHGRP data submission revisions); these sources are discussed below and include hydraulically fractured (HF) gas well completions, production segment miscellaneous flaring, production segment pneumatic controllers, liquids unloading, production segment storage tanks, G&B stations, acid gas removal (AGR) vents and flares at gas processing plants, and gas engines in the production and processing segments. Lastly, for HF gas well workovers, year 2017 emissions estimates are noticeably higher than previous years; the factors driving this increase are described below.

The combined impact of revisions to 2016 natural gas sector CH_4 emissions, compared to the previous Inventory, is an increase from 163.5 to 165.7 MMT CO_2 Eq. (2.2 MMT CO_2 Eq., or 1 percent). The recalculations resulted in an average increase in CH_4 emission estimates across the 1990 through 2016 time series, compared to the previous Inventory, of 0.6 MMT CO_2 Eq., or 0.4 percent.

The combined impact of revisions to 2016 natural gas sector CO_2 emissions, compared to the previous Inventory, is minimal, with emissions of approximately 25.5 MMT CO_2 in both Inventories. The recalculations resulted in an average increase in emission estimates across the 1990 through 2016 time series, compared to the previous Inventory, of 0.2 MMT CO_2 Eq., or 0.7 percent.

In [REF _Ref510007075 \h * MERGEFORMAT] and [REF _Ref510007088 \h * MERGEFORMAT] below are categories in Natural Gas Systems with recalculations resulting in a change of greater than 0.05 MMT CO_2 Eq., comparing the previous estimate for 2016 to the current (recalculated) estimate for 2016. For more information, please see the Recalculations Discussion below.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: Recalculations of CO_2 in Natural Gas Systems (MMT CO_2)

Stage and Emission Source	*Previous Estimate Year 2016, 2018 Inventory*	Current Estimate Year 2016, 2019 Inventory	Current Estimate Year 2017, 2019 Inventory
Exploration	***0.1***	**0.2**	**0.5**
HF Completions	*0.1*	0.2	0.5
Production	***3.2***	**3.2**	**2.8**
Gathering Pipelines	+	+	+
Miscellaneous Flaring	*1.1*	1.2	1.1
Tanks	*1.2*	1.1	0.6
HF Workovers	+	0.1	0.4
Processing	***22.0***	**21.7**	**22.5**
AGR Vents	*16.6*	16.5	16.7
Flares	*5.4*	5.2	5.7
Transmission and Storage	***0.1***	**0.4**	**0.5**
LNG Storage	+	+	+
LNG Import/Export Terminals	+	0.2	0.4
Pipeline Blowdowns	+	+	+
Distribution	+	+	+
Total	***25.5***	**25.5**	**26.3**

+ Does not exceed 0.05 MMT CO_2.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: Recalculations of CH_4 in Natural Gas Systems (MMT CO_2 Eq.)

Stage and Emission Source	*Previous Estimate Year 2016, 2018 Inventory*	Current Estimate Year 2016, 2019 Inventory	Current Estimate Year 2017, 2019 Inventory
Exploration	***0.7***	**0.7**	**1.2**
Production	***106.8***	**107.1**	**108.4**
G&B Stations	*53.7*	53.6	55.5
Gathering Pipelines	*4.0*	3.8	4.0
Pneumatic Controllers	*26.3*	26.6	26.4
Liquids Unloading	*3.3*	3.3	2.9
HF Workovers	*0.4*	0.4	0.8
Gas Engines	*2.7*	3.0	2.8
Processing	***11.2***	**11.4**	**11.7**
Gas Engines	*6.1*	6.3	6.4
Transmission and Storage	***32.8***	**34.5**	**32.4**
LNG Storage	*1.8*	0.2	0.3
LNG Import/Export Terminals	*0.3*	0.4	0.4
Pipeline Blowdowns	*4.6*	6.3	4.6
Distribution	***12.0***	**12.0**	**11.9**
Total	***163.5***	**165.7**	**165.6**

Exploration

Well Drilling (Methodological Update)

EPA updated the methodology for estimating the number of gas wells drilled across the time series to use DrillingInfo data (DrillingInfo 2018). The new methodology is detailed in the *Nov. 2018 Other Updates* memo. In previous Inventories, the U.S. Department of Energy's Energy Information Administration (DOE/EIA) *Monthly Energy Review* well drilling activity data set was used to develop well drilling activity inputs, but this publication does not provide data after year 2010. EPA therefore developed a methodology of analyzing DrillingInfo data to estimate counts of gas wells drilled in each time series year, 1990 through 2017. These activity data for select years are shown in [REF _Ref536777454 \h] below.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: Count of Gas Wells Drilled

Activity	1990	2005	2013	2014	2015	2016	2017
Gas Wells Drilled	17,805	27,568	5,681	5,871	3,585	2,264	2,264
Previous Estimate	*15,096*	*31,969*	*18,837[a]*	*18,837[a]*	*18,837[a]*	*18,837[a]*	*NA*

a – Year-specific data not available; the year 2010 estimate was assigned as a surrogate value.
NA (Not Applicable)

HF Gas Well Completions (Recalculation with Updated Data)

HF gas well completion CO_2 emissions increased 47 percent in the current Inventory for year 2016, compared to the previous Inventory, due to GHGRP submission revisions. Specifically, the GHGRP submission revisions reported higher CO_2 emissions for HF reduced emission completions with flaring, which led to a larger CO_2 emission factor. For 1990 to 2015, the CO_2 emissions increased by an average of only 0.3 percent.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: HF Gas Well Completions National CO_2 Emissions (kt CO_2)

Source	1990	2005	2013	2014	2015	2016	2017
HF Completions - Non-REC with Venting	10	27	11	2	+	+	+
HF Completions - Non-REC with Flaring	390	1,316	324	327	58	12	37
HF Completions - REC with Venting	NO	3	2	+	1	+	1
HF Completions - REC with Flaring	NO	394	929	502	218	164	438
Total Emissions	**400**	**1,741**	**1,265**	**832**	**277**	**177**	**475**
Previous Estimate	*397*	*1,748*	*1,148*	*844*	*277*	*120*	*NA*

NO (Not Occurring)
NA (Not Applicable)
+ Does not exceed 0.5 kt CO_2.

Production

Gathering Pipelines (Methodological Update)

EPA developed new activity data and net emission factors for gathering pipeline sources (leaks and blowdowns) using GHGRP data, as detailed in the *Oct. 2018 G&B* memo. Accordingly, the updated methodology no longer incorporates data on the Gas STAR reductions from pipeline leaks. Using GHGRP data to estimate gathering pipeline emissions was supported by stakeholder feedback, in response to the *Oct. 2018 G&B* memo. Gathering pipeline CH_4 emissions decreased in recent years due to the newly calculated emission factors from GHGRP and increased in early years due to updated well count activity data that drives pipeline mileage estimates. On average, CH_4 emissions decreased by approximately 6 percent across the 1990 to 2016 time series. Gathering pipeline CO_2 emissions decreased by approximately 10 percent across the 1990 to 2016 time series. See the *Oct. 2018 G&B* memo for additional discussion.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: Gathering Pipelines National CH_4 Emissions (Metric Tons CH_4)

Source	1990	2005	2013	2014	2015	2016	2017
G&B Pipeline Leaks	78,425	117,182	138,669	137,477	136,513	136,776	141,577
G&B Pipeline Blowdowns	8,436	12,605	14,917	14,788	14,685	14,713	19,777
Total Emissions	**86,861**	**129,787**	**153,586**	**152,266**	**151,198**	**151,489**	**161,354**
Previous Estimate	*85,413*	*136,627*	*164,443*	*164,727*	*162,796*	*160,311*	*NA*

NA (Not Applicable)

Gathering and Boosting Stations (Recalculation with Updated Data)

G&B station CH_4 emissions decreased by 0.3 percent in the current Inventory for year 2016, compared to the previous Inventory. This change was not the result of a methodological update, but due to updated data for marketed onshore gas production, which drives the station count activity data. EPA presented approaches to use GHGRP data to estimate G&B station emissions in the *Oct. 2018 G&B* memo, but stakeholder feedback supported maintaining the current Inventory methodology. Additional G&B station considerations for future Inventories, particularly for estimating CO_2 and N_2O emissions, are discussed in the Planned Improvements section below.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: Gathering Stations National CH_4 Emissions (Metric Tons CH_4)

Source	1990	2005	2013	2014	2015	2016	2017
Gathering and Boosting Stations	956,870	1,107,208	1,730,573	1,877,554	1,968,205	1,949,925	2,018,566
G&B Station Episodic Events	94,905	109,816	171,643	186,221	195,212	193,399	200,207

Total Emissions	**1,051,775**	**1,217,024**	**1,902,216**	**2,063,775**	**2,163,417**	**2,143,324**	**2,218,773**
Previous Estimate	*1,051,775*	*1,217,024*	*1,902,216*	*2,063,775*	*2,163,417*	*2,149,065*	*NA*

NA (Not Applicable)

Miscellaneous Production Flaring (Recalculation with Updated Data)

Miscellaneous production flaring CO_2 emissions decreased in the current Inventory for 1990 to 2015 and increased in the current Inventory for 2016, compared to the previous Inventory. The CO_2 emissions changes are due to GHGRP submission revisions and use of GHGRP well counts from the facility overview table (see the Well Counts discussion below). In addition, the emission calculations are performed at a basin-level, and the changes impacted each basin uniquely.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: Miscellaneous Production Flaring National Emissions (kt CO_2)

Source	1990	2005	2013	2014	2015	2016	2017
Miscellaneous Flaring-Gulf Coast Basin	NO	155	250	296	331	243	193
Miscellaneous Flaring-Williston Basin	NO	+	+	+	+	NO	10
Miscellaneous Flaring-Permian Basin	NO	256	434	535	644	506	579
Miscellaneous Flaring-Other Basins	NO	118	293	319	343	438	308
Total Emissions	**NO**	**530**	**978**	**1,150**	**1,317**	**1,186**	**1,090**
Previous Estimate	*NO*	*572*	*1,057*	*1,241*	*1,415*	*1,129*	*NA*

NO (Not Occurring)
NA (Not Applicable)
+ Does not exceed 0.5 kt CO_2.

Gas Engines (Recalculation with Updated Data)

Natural gas engine CH_4 emissions increased in the current Inventory by an average of approximately 4 percent across the time series, compared to the previous Inventory. This change was due to the updated DrillingInfo gas wells counts (see the Well Counts discussion below).

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: Production Segment Gas Engines National Emissions (Metric Tons CH_4)

Source	1990	2005	2013	2014	2015	2016	2017
Gas Engines	116,539	123,210	131,262	128,812	125,437	118,462	113,758
Previous Estimate	*116,508*	*117,852*	*121,827*	*118,818*	*114,774*	*106,423*	*NA*

NA (Not Applicable)

Pneumatic Controllers (Recalculation with Updated Data)

Pneumatic controller CH_4 emissions increased in the current Inventory by an average of approximately 2 percent across the time series, compared to the previous Inventory. This change was impacted by several factors: GHGRP submission revisions, the use of GHGRP well counts from the facility overview table (see the Well Counts discussion below), a correction to the linear interpolation calculation for activity factors in years 1993 through 2010, and updated DrillingInfo gas well counts (see the Well Counts discussion below).

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: Production Segment Pneumatic Controller National Emissions (Metric Tons CH_4)

Source	1990	2005	2013	2014	2015	2016	2017
Low Bleed	NO	23,541	27,554	32,330	30,455	32,646	33,944
High Bleed	297,952	450,013	177,784	129,712	101,930	107,162	107,398
Intermittent Bleed	194,302	531,907	970,065	927,297	943,216	924,261	915,961
Total Emissions	**492,254**	**1,005,461**	**1,175,402**	**1,089,339**	**1,075,601**	**1,064,069**	**1,057,303**

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Previous Estimate	*506,905*	*981,773*	*1,134,147*	*1,072,375*	*1,055,935*	*1,053,207*	*NA*

NO (Not Occurring)
NA (Not Applicable)

Liquids Unloading (Recalculation with Updated Data)

Liquids unloading CH_4 emissions increased for 2015 and decreased for 2016 in the current Inventory, compared to the previous Inventory. On average across the time series, liquids unloading CH_4 emissions increased by approximately 2 percent. These changes were due to GHGRP submission revisions and the use of GHGRP well counts from the facility overview table (see the Well Counts discussion below). In particular, the percent of gas wells requiring liquids unloading increased for the GHGRP reporting year 2015 data (which is applied to all prior years of the time series) and decreased for reporting year 2016.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: Liquids Unloading National Emissions (Metric Tons CH_4)

Source	1990	2005	2013	2014	2015	2016	2017
Unloading with Plunger Lifts	NO	126,009	124,036	80,880	63,089	61,397	46,843
Unloading without Plunger Lifts	372,325	247,433	110,095	129,904	97,616	69,381	70,536
Total Emissions	**372,325**	**373,442**	**234,132**	**210,784**	**160,706**	**130,778**	**117,379**
Previous Estimated Emissions	*379,837*	*365,310*	*220,990*	*202,745*	*153,975*	*132,871*	*NA*

NO (Not Occurring)
NA (Not Applicable)

Tanks (Recalculation with Updated Data)

Production tank CO_2 emissions increased by an average of approximately 30 percent across 1990 to 2015 in the current Inventory and decreased by about 8 percent in the current Inventory for 2016, compared to the previous Inventory. The change in production tank CO_2 emissions is mainly driven by GHGRP submission revisions. For example, GHGRP reporting year 2015 CO_2 emissions increased, which led to an increase in the calculated emission factors, and year 2015 emission factors are applied to all prior years of the time series.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: Production Segment Storage Tanks National Emissions (kt CO_2)

Source	1990	2005	2013	2014	2015	2016	2017
Large Tanks w/Flares	287	363	984	1,030	1,041	1,080	558
Large Tanks w/VRU	NO	1	3	3	3	2	+
Large Tanks w/o Control	167	90	147	154	155	1	+
Small Tanks w/Flares	NO	8	30	31	31	33	22
Small Tanks w/o Flares	6	4	9	10	10	12	5
Malfunctioning Separator Dump Valves	+	+	+	+	+	+	1
Total Emissions	**460**	**466**	**1,173**	**1,227**	**1,240**	**1,129**	**585**
Previous Estimate	*294*	*378*	*1,030*	*1,078*	*1,089*	*1,224*	*NA*

NO (Not Occurring)
NA (Not Applicable)
+ Does not exceed 0.5 kt CO_2.

HF Gas Well Workovers (Year 2017 Emissions)

Recalculated HF gas well workover emissions did not result in large changes across the 1990 to 2016 time series when comparing the current Inventory to the previous Inventory. However, HF gas well completion emissions had a large increase in emissions for 2017, particularly for CO_2 emissions. This large increase in 2017 was mainly due to the GHGRP data reported for 2017, wherein more reduced emission workovers with flaring were conducted.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: HF Gas Well Workovers National Emissions (Metric Tons CH_4)

Source	1990	2005	2013	2014	2015	2016	2017
HF Workovers - Non-REC with Venting	25,823	66,053	69,935	25,517	2,518	7,878	11,795
HF Workovers - Non-REC with Flaring	366	1,034	350	476	225	76	527
HF Workovers - REC with Venting	NO	625	2,711	589	8,035	6,301	17,193
HF Workovers - REC with Flaring	NO	5	281	26	2,383	1,297	4,197
Total Emissions	**26,188**	**67,717**	**73,276**	**26,608**	**13,161**	**15,551**	**33,711**
Previous Estimate	*25,244*	*66,781*	*72,557*	*26,957*	*13,228*	*16,986*	*NA*

NO (Not Occurring)
NA (Not Applicable)

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: HF Gas Well Workovers National Emissions (kt CO_2)

Source	1990	2005	2013	2014	2015	2016	2017
HF Workovers - Non-REC with Venting	2	4	8	2	+	+	2
HF Workovers - Non-REC with Flaring	66	187	70	156	17	12	41
HF Workovers - REC with Venting	NO	+	+	+	+	+	+
HF Workovers - REC with Flaring	NO	1	55	5	59	47	313
Total Emissions	**68**	**193**	**133**	**163**	**77**	**59**	**356**
Previous Estimate	*65*	*190*	*125*	*156*	*77*	*44*	*NA*

NO (Not Occurring)
NA (Not Applicable)
+ Does not exceed 0.5 kt CO_2.

Well Counts (Recalculation with Updated Data)

For total national well counts, EPA has used a more recent version of the DrillingInfo data set (DrillingInfo 2018) to update well counts data in the Inventory. EPA also updated the DrillingInfo data processing methodology to more accurately count wells in states with lease-level reporting (e.g., Kansas), which resulted in slight increased counts across the time series. While this was not a significant recalculation (increases are 2 to 3 percent across the time series), this is a key input to the Inventory, so results are highlighted here.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: Producing Gas Well Count Data

Activity	1990	2005	2013	2014	2015	2016	2017
Number of Gas Wells	193,718	346,862	428,947	424,308	420,418	419,005	411,450
Previous Estimate	*197,626*	*348,470*	*427,828*	*431,446*	*425,651*	*416,881*	*NA*

NA (Not Applicable)

In October 2018, EIA released an updated time series of national oil and gas well counts (covering 2000 through 2017). EIA estimates 991,000 total producing wells for year 2017. EPA's total well count for this year is 978,176. EPA's well counts in recent time series years are generally 2 percent lower than EIA's. EIA's well counts include side tracks, completions, and recompletions, and therefore are expected to be higher than EPA's which include only producing wells. EPA and EIA use a different threshold for distinguishing between oil versus gas (EIA uses 6 mcf/bbl, while EPA uses 100 mcf/bbl), which results in EIA having a lower fraction of oil wells and a higher fraction of gas wells than EPA.

For the count of wells included in GHGRP reporting (used to develop wellhead-based emissions and activity factors), EPA previously referenced the wellhead counts contained within the reporting table for onshore production equipment leak emissions. Due to updated reporting requirements for year 2017 forward, well counts provided as

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part of the facility overview information (i.e., wells producing at the end of the calendar year plus wells removed from production in a given year) provide more complete estimates. Therefore, EPA used well counts from the facility overview table for source-specific methodologies that rely on GHGRP reported well counts in the current Inventory. Comparing the GHGRP well counts from the facility overview table to the equipment leaks table: a larger population of the wells were reported as "oil" production type in the facility overview information table, compared to the equipment leaks table, which generally led to decreased activity and emissions for natural gas systems; for example, as discussed in the sections above, production segment emissions from pneumatic controllers and miscellaneous production flaring decreased across most of the time series.

Processing

Acid Gas Removal (Recalculation with Updated Data)

Acid gas removal unit (AGR) CO_2 emissions were essentially unchanged across the 1990 to 2015 time series, comparing the current Inventory to the previous Inventory, with an average increase of less than 0.01 percent. There was a decrease in CO_2 emissions for 2016, comparing the current Inventory to the previous Inventory. This decrease in CO_2 emissions for 2016 is due to GHGRP submission revisions, where a lower emission factor was calculated from the GHGRP data.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: AGR National CO_2 Emissions (kt CO_2)

Source	1990		2005		2013	2014	2015	2016	2017
Acid Gas Removal	28,282		15,320		14,565	14,946	14,946	16,481	16,728
Previous Estimate	*28,282*		*15,320*		*14,565*	*14,946*	*14,946*	*16,565*	*NA*

NA (Not Applicable)

Flares (Recalculation with Updated Data)

Processing segment flare CO_2 emissions increased by only 0.03 percent across the 1990 to 2015 time series in the current Inventory and decreased by approximately 4 percent for 2016 in the current Inventory, compared to the previous Inventory. This decrease in CO_2 emissions for 2016 is due to GHGRP submission revisions, where a lower emission factor was calculated from the GHGRP data.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: Processing Segment Flares National CO_2 Emissions (kt CO_2)

Source	1990		2005		2013	2014	2015	2016	2017
Flares	NO		3,517		5,904	6,058	6,058	5,203	5,683
Previous Estimate	*NO*		*3,516*		*5,902*	*6,056*	*6,056*	*5,404*	*NA*

NO (Not Occurring)
NA (Not Applicable)

Gas Engines (Recalculation with Updated Data)

Gas engine CH_4 emissions increased by approximately 0.1 percent across the 1990 to 2015 time series in the current Inventory and increased by approximately 3 percent for 2016 in the current Inventory, compared to the previous Inventory. This increase in CH_4 emissions for 2016 is due to GHGRP submission revisions, where a higher activity factor (MMhphr/plant) was calculated from the GHGRP data.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: Processing Segment Gas Engines National Emissions (Metric Tons CH_4)

Source	1990		2005		2013	2014	2015	2016	2017
Gas Engines	137,102		169,388		228,152	234,119	234,119	250,368	255,822
Previous Estimate	*137,102*		*169,101*		*227,671*	*233,626*	*233,626*	*242,451*	*NA*

NA (Not Applicable)

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Transmission and Storage

Transmission Pipeline Blowdowns (Methodological Update)

EPA developed new CH_4 and CO_2 emission factors for transmission pipeline blowdowns using GHGRP data, as detailed in the *Nov. 2018 Other Updates* memo. In response to stakeholder comments on the Public Review draft, EPA applied year-specific emission factors calculated from GHGRP data for years 2016 forward and retained historical emission factors for earlier years. As a result, compared to the previous Inventory, calculated CH_4 emissions from this source increased by 37 percent for year 2016 and remained constant over the rest of the time series, while CO_2 emissions increased by 33 percent for year 2016. See the *Nov. 2018 Other Updates* memo for additional discussion and the Planned Improvements section below for considerations for future Inventories.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: Transmission Pipeline Blowdowns National CH_4 Emissions (Metric Tons CH_4)

Source	1990	2005	2013	2014	2015	2016	2017
Pipeline Blowdowns	177,951	183,159	184,628	183,984	183,583	250,175	184,455
Previous Estimate	*177,951*	*183,159*	*184,596*	*183,973*	*183,538*	*183,081*	*NA*

NA (Not Applicable)

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: Transmission Pipeline Blowdowns National CO_2 Emissions (kt CO_2)

Source	1990	2005	2013	2014	2015	2016	2017
Pipeline Blowdowns	5	5	5	5	5	7	5
Previous Estimate	*5*	*5*	*5*	*5*	*5*	*5*	*NA*

NA (Not Applicable)

LNG Storage (Methodological Update)

For LNG storage facilities, EPA updated the Inventory methodology to use available GHGRP data paired with updated activity estimates, as detailed in the *Oct. 2018 LNG* memo. EPA developed facility-level average CH_4 and CO_2 emission factors that represent emissions from station fugitives, compressor vented and fugitive sources, and flaring using combined GHGRP data from years 2015 through 2017 and applied these emission factors across the time series. To estimate LNG storage station CH_4 and CO_2 blowdown emissions, EPA maintained the current Inventory emission factors. For activity data (storage station counts), EPA used the existing estimates for years 1990 through 2009 (although the total count of complete storage stations plus satellite stations were used, not a fraction of the satellite stations like the previous Inventory methodology) and reviewed current PHMSA data in conjunction with GHGRP data to obtain a count of active storage stations for years 2010 forward. For compressor exhaust CH_4 emissions, EPA updated activity factors and maintained the current Inventory emission factors. EPA developed average activity factors (i.e., MMhphr/station for each compressor driver type) using combined GHGRP data from years 2015 through 2017 and applied these activity factors across the time series. These updates resulted in an average decrease of 86 percent in CH_4 emissions across the time series and CO_2 emissions increased by an average factor of approximately 17 across the time series.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: LNG Storage Station National CH_4 Emissions (Metric Tons CH_4)

Source	1990	2005	2013	2014	2015	2016	2017
LNG storage stations	1,138	1,396	1,411	1,411	1,425	1,382	1,396
LNG storage station blowdowns	6,571	8,060	8,144	8,144	8,228	7,976	8,060
LNG storage engines	476	584	590	590	596	578	584
LNG storage turbines	26	32	33	33	33	32	32
Total Emissions	**8,212**	**10,072**	**10,177**	**10,177**	**10,282**	**9,967**	**10,072**
Previous Estimate	*63,258*	*73,124*	*73,124*	*73,124*	*73,124*	*73,124*	*NA*

NA (Not Applicable)

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Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: LNG Storage Station National CO_2 Emissions (kt CO_2)

Source	1990	2005	2013	2014	2015	2016	2017
LNG storage stations	36	45	45	45	45	44	45
LNG storage station blowdowns	+	+	+	+	+	+	+
Total Emissions	**37**	**45**	**45**	**45**	**46**	**44**	**45**
Previous Estimate	*2*	*2*	*2*	*2*	*2*	*2*	*NA*

NA (Not Applicable)

LNG Import/Export Terminals (Methodological Update)

For LNG terminals, EPA updated the Inventory methodology to use available GHGRP data paired with updated activity estimates, as detailed in the *Oct. 2018 LNG* memo. This methodological update also resulted in the creation of a new category for export terminals in the Inventory; previously, emissions were only estimated for import terminals. EPA used GHGRP data to develop facility-level CH_4 and CO_2 emission factors that represent emissions from station fugitives, blowdowns, compressor vented and fugitive sources, and flaring. EPA developed these facility-level emission factors for two categories of facilities: import-only terminals (import terminals) and terminals with export capability (export terminals). For import terminals, EPA calculated average CH_4 and CO_2 emission factors using combined GHGRP data from years 2015 through 2017 and applied these emission factors across the time series. For export terminals, EPA used year-specific GHGRP CH_4 and CO_2 data for 2015 through 2017 to develop emission factors and applied the year 2015 emission factors to prior time series years. For import terminals activity data, EPA used the existing Inventory import terminal counts for years 1990 through 2003 and reviewed current DOE data in conjunction with GHGRP data to obtain a count of existing import terminals for years 2004 forward. For export terminals activity data, EPA reviewed current DOE data in conjunction with GHGRP data to obtain a count of existing terminals with export capability across the time series. For compressor exhaust CH_4 emissions, EPA updated activity factors and maintained the current Inventory emission factors. For import terminals compressor exhaust, EPA developed average activity factors (i.e., MMhphr/station for each compressor driver type) using combined GHGRP data from years 2015 through 2017 and applied these factors across the time series. For export terminals compressor exhaust, EPA used year-specific GHGRP activity data for 2015 through 2017 to develop activity factors (i.e., MMhphr/station for each compressor driver type) and applied the year 2015 activity factors to prior time series years. These LNG terminal updates resulted in an average increase of 8 percent in CH_4 emissions across the time series and CO_2 emissions increased by an average factor of approximately 286 across the time series, when comparing the emissions from import and export terminals in the current Inventory to emissions from import terminals in the previous Inventory.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: LNG Import/Export Terminal National CH_4 Emissions (Metric Tons CH_4)

Source	1990	2005	2013	2014	2015	2016	2017
LNG Import Terminals Misc. Sources[a]	114	284	625	625	625	568	568
LNG Import Terminal Blowdowns	2,635	6,587	14,491	14,491	14,491	13,174	13,174
LNG Import Terminal Engines	226	566	1,245	1,245	1,245	1,132	1,132
LNG Import Terminal Turbines	+	+	+	+	+	+	+
LNG Export Terminals Misc. Sources[a]	801	801	801	801	801	350	1,014
LNG Export Terminal Blowdowns	+	+	+	+	+	52	NO
LNG Export Terminal Engines	NO	NO	NO	NO	NO	85	NO
LNG Export Terminal Turbines	11	11	11	11	11	1	1
Total Emissions	**3,787**	**8,249**	**17,174**	**17,174**	**17,174**	**15,363**	**15,889**
Previous Estimate[b]	*3,341*	*15,445*	*10,902*	*10,190*	*10,801*	*10,741*	*NA*

[a] Equipment leaks, compressor vented and leak emissions, and flares.
[b] Includes emissions from LNG import terminals only.
NO (Not Occurring)
NA (Not Applicable)

+ Does not exceed 0.5 MT CH_4.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: LNG Import/Export Terminal National CO_2 Emissions (kt CO_2)

Source	1990	2005	2013	2014	2015	2016	2017
LNG Import Terminals Misc. Sources[a]	15	37	80	80	80	73	73
LNG Import Terminal Blowdowns	+	+	1	1	1	1	1
LNG Export Terminals Misc. Sources[a]	+	+	+	+	+	98	278
LNG Export Terminal Blowdowns	NO	NO	NO	NO	NO	+	NO
Total Emissions	**15**	**37**	**81**	**81**	**81**	**172**	**352**
Previous Estimate	+	+	+	+	+	+	*NA*

[a] Equipment leaks, compressor vented and leak emissions, and flares.
[a] Includes emissions from LNG import terminals only.
NO (Not Occurring)
NA (Not Applicable)
+ Does not exceed 0.5 kt CO_2.

Distribution

There were no methodological updates to the distribution segment, but there were recalculations due to updated data (e.g., GHGRP M&R station counts) that resulted in an average increase in calculated emissions over the time series from this segment of 0.01 MMT CO_2 Eq. CH_4 (or 0.1 percent) and less than 0.01 MMT CO_2 (or 0.1 percent).

N_2O Emissions

EPA newly calculated N_2O emissions in the current Inventory, as discussed in the *Nov. 2018 Other Updates* memo. Prior Inventories did not calculate N_2O emissions from natural gas systems. For each flaring emission source calculation methodology which uses GHGRP data, the existing source-specific methodology was applied to calculate N_2O emission factors. This update was applied for sources in the exploration, production, processing, and transmission and storage segments.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: N_2O National Emissions (Metric Tons N_2O)

Activity	1990	2005	2013	2014	2015	2016	2017
Exploration	**1.5**	**4.7**	**4.0**	**2.9**	**10.8**	**0.4**	**1.0**
Non-completion well testing - flared	0.8	1.4	1.7	1.7	1.7	NO	+
HF Completions with Flaring	0.8	3.3	2.2	1.1	8.1	0.4	0.9
Non-HF Completions with Flaring	+	+	+	+	0.9	+	+
Production	**0.5**	**3.0**	**7.8**	**6.7**	**9.3**	**3.4**	**3.1**
HF Workovers with Flaring	0.1	0.4	0.2	0.2	2.2	0.1	0.7
Non-HF Workovers with Flaring	NO	+	1.7	+	+	NO	NO
Misc. Onshore Production Flaring	NO	2.1	4.2	4.8	5.3	2.2	1.8
Tanks with Flares	0.4	0.6	1.6	1.7	1.7	1.1	0.6
Processing	**NO**	**11.2**	**18.9**	**19.4**	**19.4**	**12.8**	**10.2**
Flares	NO	11.2	18.9	19.4	19.4	12.8	10.2
Transmission and Storage	**0.9**	**1.0**	**1.1**	**1.2**	**1.2**	**1.3**	**1.5**
Transmission Flaring	0.1	0.1	0.1	0.1	0.1	+	0.1
Storage Flaring	+	+	+	+	+	0.1	+

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LNG Storage Flaring	0.7	0.8	0.8	0.8	0.8	0.8	0.8
LNG Import Terminals Flaring	+	0.1	0.2	0.2	0.2	0.1	0.1
LNG Export Terminals Flaring	NO	NO	NO	NO	NO	0.2	0.5
Distribution	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**
Total Emissions	**3.0**	**20.0**	**31.8**	**30.1**	**40.6**	**17.8**	**15.9**

NO (Not Occurring)
+ Does not exceed 0.05 MT N_2O.

Planned Improvements

EPA seeks stakeholder feedback on the improvements noted below for future Inventories.

Gathering and Boosting Stations

In the *Oct. 2018 G&B* memo, EPA presented approaches that rely on GHGRP data to estimate G&B station emissions. Stakeholder feedback received in response to the *Oct. 2018 G&B* memo supported maintaining the current Inventory approach. As such, EPA maintained the current Inventory approach to estimate G&B station emissions, and did not use a methodology that relies on GHGRP data. EPA will continue to review GHGRP data and other research that becomes available to estimate G&B station emissions. EPA also requests specific feedback on options to estimate G&B station flaring (CO_2 and N_2O) emissions and AGR (CO_2) emissions for future Inventories. The current Inventory approach does not account for the significant CO_2 emissions from flaring and AGR units. EPA plans to review available data from upcoming studies and additional years of data reported to GHGRP to improve estimated emissions from these sources. The GHGRP emissions from flaring in gathering and boosting total 3,894 kt CO_2 and 0.01 kt N_2O reported for year 2017 (2,143 kt CO_2 from miscellaneous flaring, 686 kt CO_2 from flaring from dehydrators, 579 kt CO_2 from flaring from tanks, and 486 kt CO_2 from AGR units).

Transmission Pipeline Blowdowns

For the final 2019 Inventory estimate, in response to stakeholder feedback, EPA calculated year-specific emission factors for transmission pipeline blowdowns using data from the first two years of GHGRP reporting, 2016 and 2017, and applied historical emission factors to all previous time series years. EPA is considering other approaches for future Inventories, as additional years of GHGRP data become available. EPA requests feedback on whether an updated methodology should be applied for earlier time series years (e.g., retain current emission factors for 1990 to 1992, then use linear interpolation to calculate emission factors for years 1993 through 2015; or develop an average factor from 2016 through 2018 GHGRP data to apply for 1990 through 2015). EPA also requests feedback on whether an updated methodology should be applied for later time series years (e.g., develop an average factor from 2016 through 2018 GHGRP data to apply for 2016 through 2018 time series years).

Well-Related Activity Data

As described in the Recalculations Discussion, EPA has updated the emission factors for several well-related emission sources, including testing, completions, and workovers. EPA will continue to assess available data, including data from the GHGRP and stakeholder feedback on considerations, to improve activity estimates for sources that rely on well-related activity data. For example, EPA will seek information on other data sets that might inform estimates of non-hydraulically fractured gas well completions and workovers.

Offshore Platforms

EPA is considering updates to the offshore platform emissions calculation methodology, as discussed in the *2018 Other Updates Memo*. The current emission factors were based on data from the 2011 DOI/Bureau of Ocean Energy Management's (BOEM) dataset, and 2014 BOEM data are available. A different source for platform counts is also being considered.

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Upcoming Data, and Additional Data that Could Inform the Inventory

EPA will assess new data received by the Methane Challenge Program on an ongoing basis, which may be used to confirm or improve existing estimates and assumptions.

EPA continues to track studies that contain data that may be used to update the Inventory. Key studies in progress include: DOE-funded work on vintage and new plastic pipelines (distribution segment), industrial meters (distribution segment), and sources within the gathering and storage segments[8]; an API field study on pneumatic controllers; a Pipeline Research Council International (PRCI) project in which researchers are gathering and analyzing subpart W data on transmission compressor stations and underground storage facilities; and other studies by research groups that will examine gathering and boosting emissions and offshore platform emissions. EPA will also continue to assess studies that include and compare both top-down and bottom-up estimates, and which could lead to improved understanding of unassigned high emitters (e.g., identification of emission sources and information on frequency of high emitters) as recommended in stakeholder comments.

EPA also continues to seek new data that could be used to assess or update the estimates in the Inventory. For example, stakeholder comments have highlighted areas where additional data that could inform the Inventory are currently limited or unavailable:

- Tank malfunction and control efficiency data.
- Consider updating engine emission factors, including using subpart W data to the extent possible, and considering whether and how to represent differences between rich- and lean-burn engines.
- Activity data and emissions data for production facilities that do not report to GHGRP.
- Natural gas leaks at point of use estimates.
- Anomalous leak events, such as a 2018 well blowout in Ohio.

EPA will continue to seek available data on these and other sources as part of the process to update the Inventory.

[8] See <https://www.energy.gov/under-secretary-science-and-energy/articles/doe-announces-13-million-quantify-and-mitigate-methane>.

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